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GAS-PRESSURE BONDING OF STAINLESS STEEL-REINFORCED BERYLLIUM HYPERVELOCITY IMPACT TARGETS

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BATTELLE MEMORIAL INSTITUTE

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SUMMARY REPORT

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Technical Monitor

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SUMMARY

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The gas-pressure-bonding process was successfully developed as a fabrication technique for making stainless steel-reinforced beryllium hypervelocity impact targets. Three designs for reinforcing the beryllium structures were fabricated: kinked-wire filament reinforcement, wire-mesh reinforcement, and compartmented reinforcement. Twelve tubular-shaped reinforced beryllium targets were prepared from beryllium powder and the appropriate stainless steel reinforcement. Gas-pressure-bonding conditions of 1500°F for 2 hours at 10,000 psi were utilized to densify the beryllium powder to approximately theoretical density and simultaneously bond the beryllium to the stainless steel reinforcement. All three methods studied to reinforce the beryllium were successfully fabricated and were demonstrated to be feasible. The compartmented reinforced specimens required more involved preparation than the other two designs, however. Also, cracking occurred in some of the compartmented-design specimens during final machining. The kinked-wire filament and wire-mesh reinforced structures appear very promising and practical to fabricate.

Author

INTRODUCTION

A previous program was conducted at Battelle employing the gas-pressure-bonding process for the fabrication of non-reinforced tubular beryllium impact targets with inner liner tubes of stainless steel or columbium alloy (Ref. 1). Successful fabrication techniques were developed for these targets. However, crack propagation in the beryllium targets fabricated by all methods has been a major problem. Impact by a high-velocity projectile on the surface of a tubular beryllium target will cause brittle crack propagation which diverges from the impact area.

It was considered, therefore, that the addition of reinforcement to the structure in the form of a ductile dispersion may restrict or limit the amount of cracking experienced. Work at Battelle on wire-reinforced ceramics had shown that the ductile phase in a brittle matrix absorbs much of the energy spent in cracking the brittle matrix and limits cracking.

The present program was conducted to develop techniques for gas-pressure bonding the desired reinforced structures and to prepare targets for hypervelocity impact testing. The gas-pressure-bonding process, which uses an inert gas at high temperatures and pressures to accomplish densification and bonding of materials, has been described in detail in the literature. (Refs. 2 and 3).

MATERIALS AND PROCEDURES

The beryllium powder employed in the fabrication of the hypervelocity targets was QMV grade powder from Brush Beryllium Company. Table 1 is the certified analysis of the powder supplied by the vendor. The stainless steel tube used as the liner was Type 316 and was 0.500-in. OD with 0.028-in.-thick wall. The wire mesh, wire filaments, and compartment spacers also were fabricated from Type 316 stainless steel.

TABLE 1. ANALYSIS OF BERYLLIUM

Constituent	Weight Percent
Be	98.5
BeO	1.79
Al	.09
C	.09
Fe	.12
Mg	.01
Si	.04

The targets fabricated for hypervelocity impact testing consisted of a thick-wall tube of beryllium which was lined on the inside diameter with a thin-wall tube of stainless steel. The beryllium portion of the composite had an OD of 1.225 in. and an ID of 0.500 in. As fabricated in this program, the beryllium tube containing the stainless steel reinforcement wire or compartmenting sheet was compacted from powder. This beryllium-matrix tube was lined on the inside diameter with a stainless steel tube which is 0.500-in. OD and 0.444-in. ID, and the stainless tube was bonded to the beryllium tube during the gas-pressure-bonding operation. The target length was 4 inches.

Three different designs were investigated for the fabrication of the stainless steel reinforced hypervelocity targets. In the mesh reinforced design, QMV grade powder was cold hydrostatically pressed throughout three cylindrical stainless steel meshes equally spaced within one another and concentric around the stainless steel liner tube. In the kinked-filament design, a mixture of QMV powder and 1/2-in.-long, 0.005-in.-diameter kinked wires was cold hydrostatically pressed around the stainless steel tubing. The third design employed a compartmented structure with stainless steel spacers and rings separating cold die-pressed beryllium segments. In all cases a mild steel mandrel was placed inside the stainless steel liner tube to size the inside diameter during densification. The assembled specimens were then sealed in evacuated mild steel cans and gas-pressure bonded to achieve densification of the powder composite and bonding between the beryllium and stainless steel components.

The assembly of these composite structures for hydrostatic pressing was similar to the technique described in a previous report (Ref. 1). However, to eliminate camber encountered during hydrostatic pressing in the previous program the mild steel centering wheels were replaced with rubber corks. Holes drilled in the center of the corks allowed the liner tube and mandrel to fit tightly. During hydrostatic pressing, these rubber stoppers were free to move, eliminating the camber.

The hypervelocity targets were gas-pressure bonded at 1500°F for 2 hours at 10,000 psi. The general procedures and equipment used have been described in the literature. (Refs. 2 and 3). After bonding, the mild steel cans and inside mandrel were removed from the targets by an acid pickel consisting of an aqueous 50 volume percent nitric acid solution maintained at 120°F. The beryllium targets were then machined and hand polished to final dimensions. The appearance of one of the targets after final machining is shown in Figure 1. Evaluation in this program consisted only of appraisal of techniques during development of the fabrication procedures and visual examination of the specimens.

KINKED-WIRE REINFORCED TARGETS

The kinked-wire filaments for this composite structure, which are illustrated in Figure 2, were fabricated from Type 316 stainless steel wire, 0.005-in. in diameter. Each fiber was 1/2-in. long and kinked 90 degrees at the center. In order to fabricate the filaments, the stainless steel wire was continuously wrapped around a square steel bar, and clamps were applied to hold the wire in place. Then, a small cut-off wheel was used to cut the filaments to size. Approximately 15,000 ft. of wire was fabricated into kinked filaments.

The beryllium powder and kinked-wire filaments were vibratory packed into the assembly. Approximately 10 volume percent of the assembly was wire filaments. After pressure bonding, this percentage would become approximately 15 percent based on densification of the beryllium powder. The specimens were hydrostatically pressed at 75,000 psi. Then the specimens were rough machined, and canned in mild steel. They were evacuated to an atmosphere of about 10 microns prior to gas-pressure bonding.

The beryllium armor reinforced with the kinked-wire filaments was successfully fabricated and appears to be a very promising structure. During the fabrication of this design, the assembly, cold pressing, preliminary machining, gas-pressure compaction, and final machining of the targets were all readily accomplished. Fabrication of the kinked wires also appears to be practical for producing large numbers of filaments.

Improved techniques for cold hydrostatic pressing of the specimens were developed in this program and used to cold compact the kinked wire and the mesh reinforced targets. The previously encountered problem of longitudinal camber was eliminated in the hydrostatically pressed specimens in this program. This was accomplished by the use of the movable end components during hydrostatic pressing as described previously.

WIRE-MESH REINFORCED TARGETS

The wire-mesh reinforced design incorporated three wire-mesh tubes centered around the stainless steel liner tube. The inner mesh tube was about 0.500 in. in diameter, the middle mesh tube 0.750 in. in diameter, and the outer mesh tube 1.000 in. in diameter. The mesh tubes were centered by means of stainless steel wire interwoven throughout the mesh and liner tube. Figure 3 shows the mesh and liner tubing. The mesh was 16 by 16 wires per inch woven from 0.025-in.-diameter Type 316 stainless steel wire. The QMV beryllium powder was loaded throught the reinforcement structure and the composite was cold hydrostatically pressed at 75,000 psi. The specimens were then machined to size to fit in a mild steel can for gas-pressure bonding.

These targets were also successfully fabricated. As mentioned in connection with the kinked-filament reinforced structures, the improved hydrostatic pressing procedures produced specimens without significant camber or other distortion. Based on this and the other developments and observation during the preparation of these specimens, fabrication of this type of structure appears practical.

After final machining of one of the targets, it was noted that the wire mesh was off-center at one end. The shift off-center occurred either during hydrostatic pressing or gas-pressure bonding. This can easily be corrected in any future specimen by interweaving more stainless wire during centering of the mesh.

COMPARTMENTED REINFORCED TARGETS

In this design, longitudinal and circumferential stainless steel spacers which were 10 mils thick were assembled around the stainless steel liner tube at 1/2-in. intervals. Beryllium segments, 1/2 in. thick were cold pressed in a die at 80,000 psi from QMV powder. Figure 4 is a photograph of the die and punches and Figure 5 illustrates a cold-pressed beryllium segment. The segments were then inserted between the stainless steel spacers, which are illustrated as an assembled unit in Figure 6. Holes were drilled in the spacers to allow contact and bonding of the adjacent beryllium segments. Each target required 48 segments. After the structure was assembled, it was canned in mild steel in preparation for pressure bonding.

The compartmented reinforced targets do not appear as promising as the other two designs. The pressed beryllium segments did not densify uniformly during pressure bonding and, as a result, two of the targets prepared were undersize after machining. Also, the other two targets prepared of this design fractured during final machining. The fracture occurred between the stainless steel webbing and the beryllium segments. It was also found that the time required for component preparation and assembly of this design was significantly longer than for either of the other two designs.

Based on the prepared compartmented targets, however, the fabrication of this design still appears feasible. This type of structure would require more development of fabrication techniques than the other two designs, and would be inherently more expensive to produce. Also, it should be noted that the fracture of two of these compartmented targets during final machining may indicate that the structure does not have the desired hypervelocity impact resistance.

CONCLUSIONS

The following conclusions concerning the fabrication of the stainless steel reinforced beryllium targets are based primarily on observations made during processing of the targets and on visual examination of the fabricated targets:

1. Satisfactory techniques were developed for the fabrication by gas-pressure bonding of stainless steel-reinforced beryllium targets. The beryllium targets fabricated were fully dense and easily machined and polished after gas-pressure bonding.

2. Movable rubber end stoppers were successfully employed in the cold hydrostatic pressing operation to eliminate a previously encountered problem of longitudinal camber of the stainless steel liner tube.

3. The kinked-wire filament and wire-mesh reinforced designs appear very promising and practical to fabricate. Further development should consist of optimizing the fabrication techniques developed and the composition and geometry of these reinforced structures.

4. Fabrication of the compartmented-reinforced design appears feasible but not as practical as the other two designs, and development of improved fabrication techniques would be required. Also, the properties of this structure do not appear promising, since two of the four specimens prepared of this design fractured during final machining.

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2. Paprocki, S. J., et al: "Gas-Pressure Bonding", DMIC Report No. 159 (September 25, 1961).

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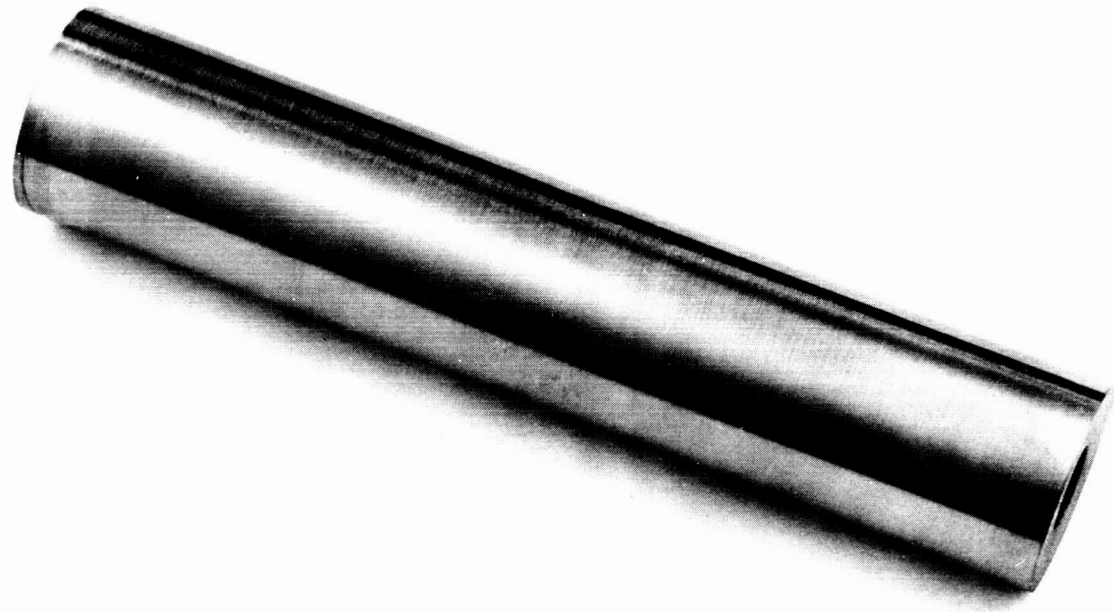

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Figure 1. - Finished hypervelocity impact target of stainless steel-reinforced beryllium. 1 1/2X.

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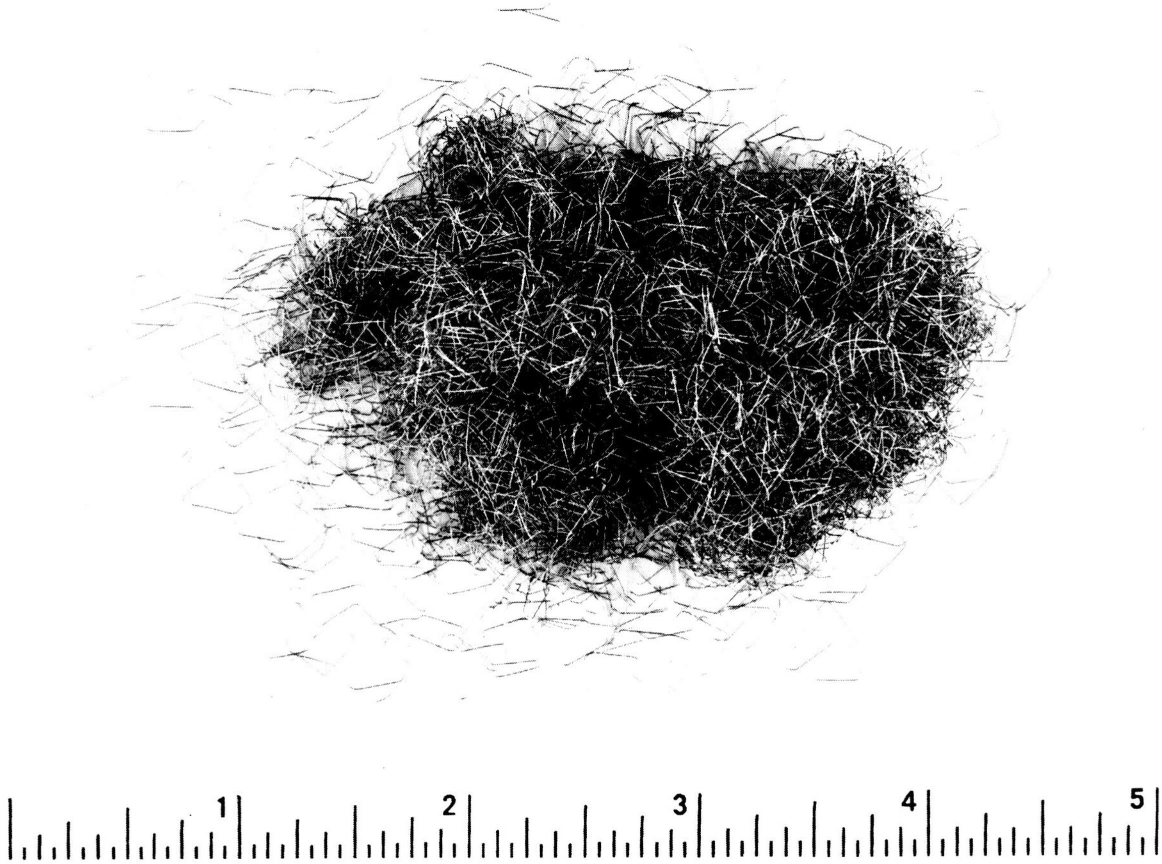

Figure 2. - Photograph of stainless steel kinked wire filaments. 1 1/2X. 11329

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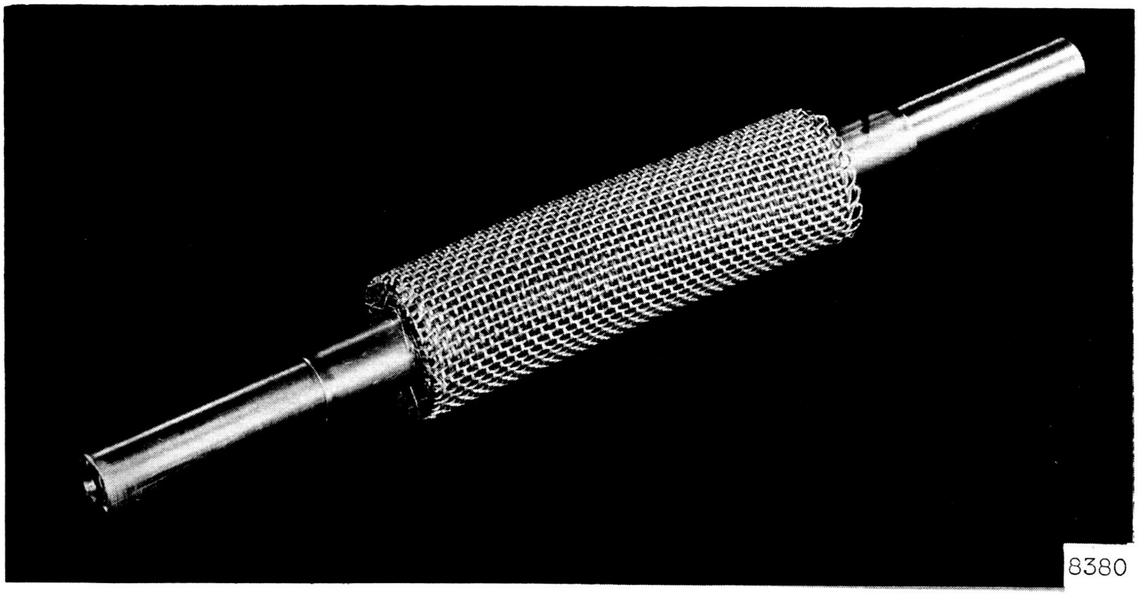

Figure 3. - Wire-mesh reinforcement centered on liner tube and mandrel. 1/2X.

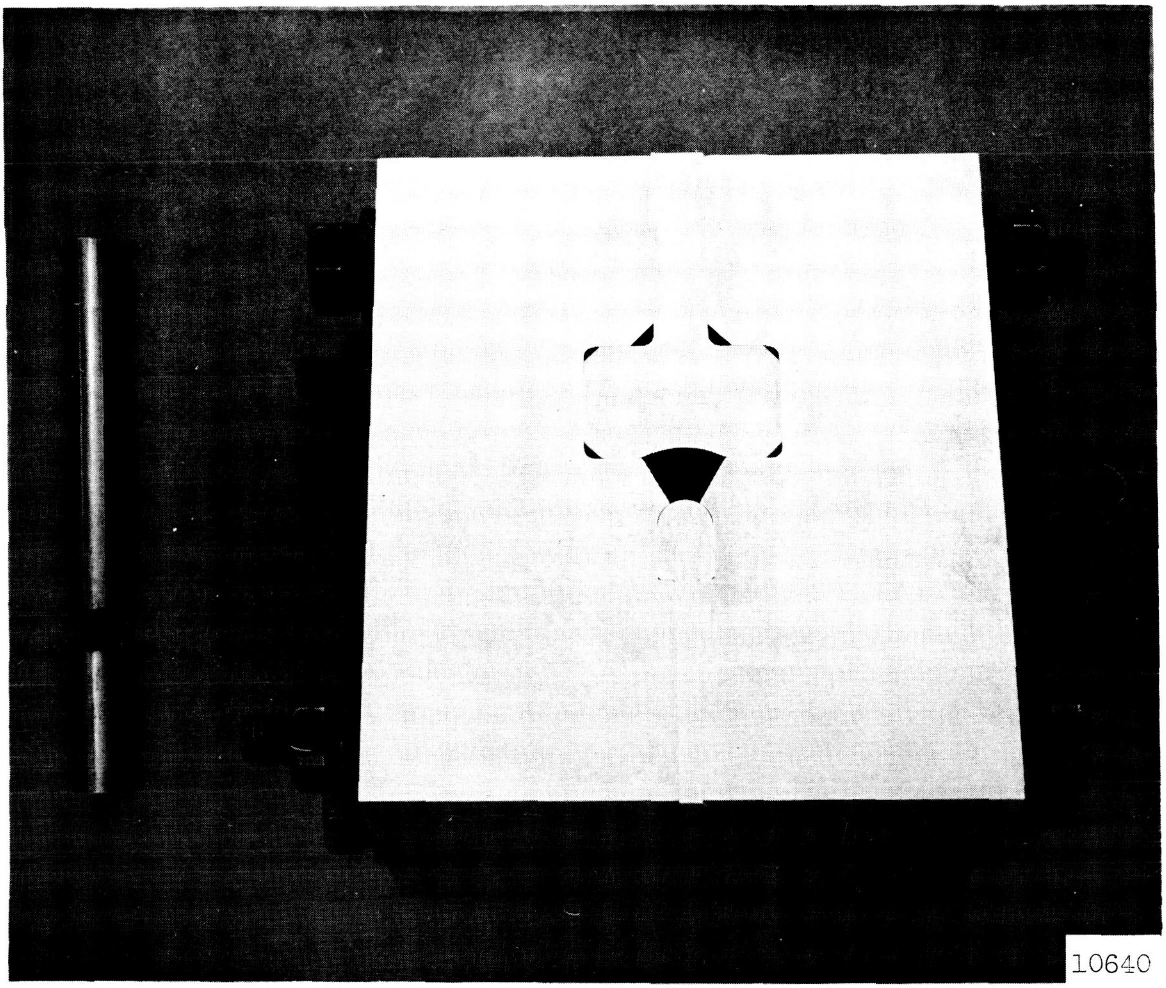

Figure 4. - Four-piece cold-pressing die and punches. 1/2X.

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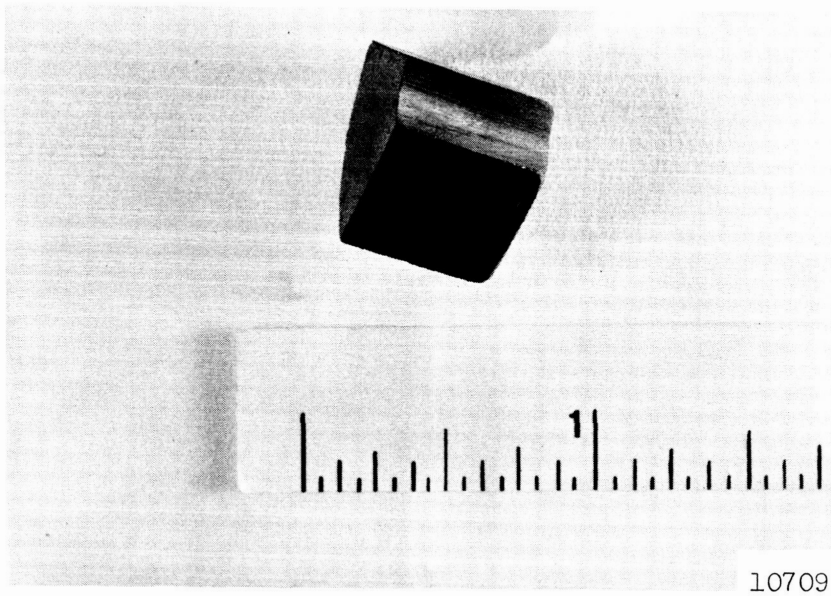

Figure 5. - Cold-pressed beryllium segment. 2 1/2X.

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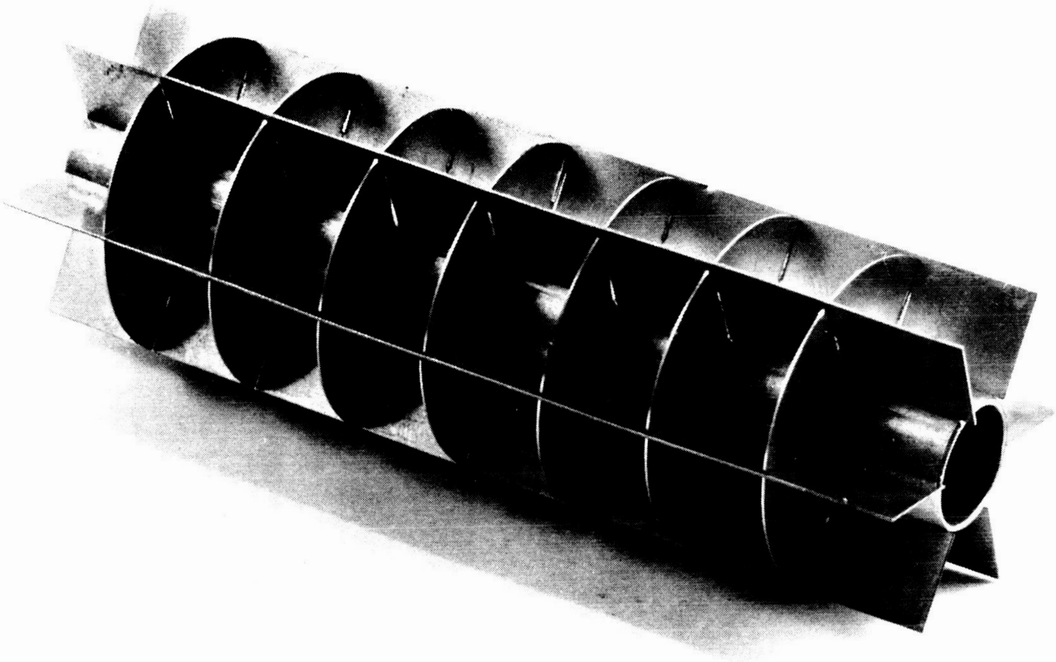

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Figure 6. - Stainless steel compartmented structure. 1 1/2X.

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Battelle Memorial Institute

ABSTRACT

Three configurations of tubular stainless steel reinforced beryllium hypervelocity impact targets were successfully bonded by the gas-pressure process. Target dimensions were nominally 1.225-inch O.D. by .50-inch I.D. by 4.0 inches long. Satisfactory bonding was achieved on four specimens each of kinked-wire and mesh-reinforced composites, while a compartmented configuration exhibited incomplete bonding on two out of the four specimens. Process details are described but no attempt was made to optimize bonding parameters or analyze the bonds produced.